

Health Care Robotics: A Progress Report

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Abstract

This paper describes the approach followed in the design of a service robot for health care applications. Under the auspices of the NASA Technology Transfer Program, a partnership was established between JPL and RWI, a manufacturer of mobile robots, to design and evaluate a mobile robot for health care assistance to the elderly and the handicapped. The activities of the first phase of the project include the development of a multi-modal operator interface, and the design and fabrication of a manipulator arm for the mobile robot. This paper describes the architecture of the system, the features of the manipulator arm, and the operator interface.

1 Introduction

In May 1993, the National Aeronautics and Space Administration (NASA) initiated a program of Technology Cooperation Agreements (TCA) aimed at transferring some of the technologies developed at NASA centers to industrial partners. In February 1996, the Jet Propulsion Laboratory (JPL) developed a TCA with Real World Interface, Inc. (RWI) to transfer some of its robotics technology into RWI line of mobile robots. RWI is a leading manufacturer of mobile robots and has expressed a strong interest in upgrading its product line with an articulated mechanical manipulator and an advanced operator interface. JPL has a long track record of R&D in the areas of manipulator control and operator interfaces. Researchers at JPL have developed control schemes for dexterous manipulators [16], mobile robots [8], and mobile manipulators [17]. Furthermore, advanced operator interface has been an area of active research at JPL for a decade, in particular, for command entry and data display, time delay compensation, high-fidelity calibration, and performance monitoring [6].

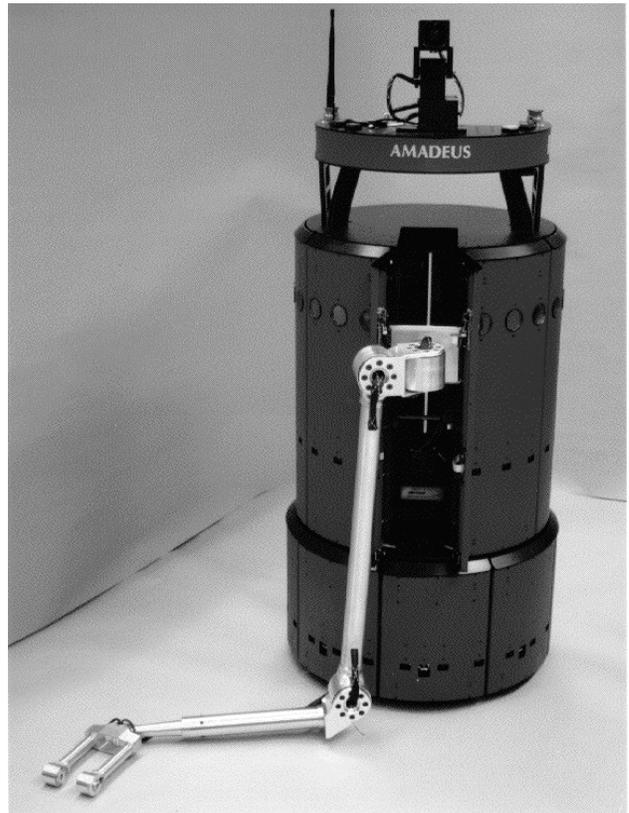


Figure 1: The Health Care Robotic system.

This paper presents a progress report on the cooperation between JPL and RWI for the development of a prototype *service robot* for health care applications.

2 Background

Service robotics is an area of research and development of increasing importance because of its potential scientific, economic, and social payoffs [15]. This area

includes robotic systems for tasks outside the industrial manufacturing arena, such as robots for sewers and electrical power tunnels inspection, robots for harvesting, construction robots, and health care robots. Technical challenges of service robotics are the unstructured environment of the applications, system reliability and serviceability, and autonomy during unsupervised operation. These robots will perform tasks that are too dangerous or demanding for humans, thus becoming tools for improving productivity and safety, rather than competitors in the workplace.

Among the many areas of service robotics, health care for assistance to the elderly and the handicapped is the one having the most promising potential. The current trend towards long-term care at home instead of in hospitals and convalescent homes, and the reduction of the staff in all medical organizations makes the development of new advanced tools for medical assistance particularly timely.

This need has not gone unnoticed, and several research projects in medical robotics are currently being pursued by academia and industry. In [4], the first commercial version of a delivery robot for hospital is described. It consists of a sensorized platform capable of unsupervised navigation in medical environments, equipped with beacons and visual markers. In [2], a prototype of a Mobile Robotic Unit for assistance to the disabled is described. This device consists of a mobile platform equipped with a dexterous manipulator, a stereo-camera and a sonar ring. The control is performed by a supervisory system connected to a graphical user interface. This system is currently being converted into a prototype suitable for testing in realistic environments. A concept of automatic medical support is described in [14], where the robotic device is the hospital room itself, equipped with sensors and actuators for recognizing, interpreting and acting upon the needs of the assisted person. Guiding principles for the design of assistive robotic systems are proposed in [9] and include the use of motion and voice commands for the robot, a distributed architecture of simple and robust devices, and enough intelligence to tolerate ambiguity and to cooperate with the user.

It is noticed in [3] that the involvement of potential users is one of the critical factors for the successful creation and utilization of a new technology. Particularly in the area of robotic systems for assisting the elderly and the handicapped, there is very little experience available to guide the design process, and most designers have no direct knowledge of the user needs. Furthermore, to ensure that there are no negative effect on the users health, the design must be developed

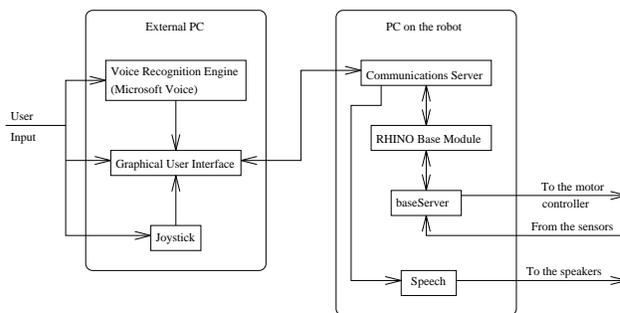


Figure 2: Health Care Robot system architecture.

in cooperation with health care professionals.

To overcome these difficulties, we relied on the advice and help of experts in long-term medical care, and carried out a preliminary investigation of the needs of this community for a robotic assistive device. The consensus reached on the health care robot is a small mobile platform equipped with a manipulator arm, a vision system, and a user interface, as shown in Figure 1. The mobile platform with its sensor systems is manufactured by RWI, and the manipulator arm and the user interface are designed and built by JPL. The system is designed with a set of functions that can be selected depending on the specific task and user, thus personalizing the performance of the robot to the specific user's needs.

In the following Section, we will first review the overall architecture of the health care robot. We briefly describe the mechanical manipulator designed for this project in Section 4. The main features of the user interface are described in Section 5. We conclude the paper with a brief discussion of this approach and with our plans for future research and development.

3 System Overview

The Health Care Robot (HCR) shown in Figure 1 consists of a mobile robotic platform manufactured by RWI, and an IBM-compatible personal computer (PC) serving as a control station. The PC software is the Windows95 operating system, selected for compatibility with commercial products, and the robot is controlled by an internal PC using the Linux operating system.

The robot is a B21 mobile platform manufactured by RWI and equipped with a color camera mounted on a pan-tilt head, and an array of ultrasound, infrared and contact sensors for autonomous navigation. The robot is powered by four lead-acid batteries providing

6 hours of continuous operation [13].

Two layers of application programs control the motion and the input-output data on the robot. The lower level is called the Base Server, and consists of a collection of device drivers supplied by RWI performing low-level motion control and sensor data acquisition. The second layer is the Rhino package [1] developed at the University of Bonn (Germany), and providing high-level trajectory control and obstacle avoidance capabilities. Rhino accepts messages from other programs and from external sources. Depending on the message type and on its parameters, Rhino sends a command to the Base Server for execution.

A communication server handles all communication between the Rhino package and the control station. This program is necessary to ensure compatibility between Rhino and Windows95, since Rhino uses the interprocess communication system TCX [5], which is incompatible with Windows95. The overall structure of the software architecture is shown Figure 2.

The first phase of the Health Care Robot project consists of design and fabrication of a manipulator arm for the mobile platform, and development of a set of tools for the user interface, as described next.

4 The Manipulator Arm

Figures 1 and 3 show the manipulator arm in its unfolded and folded positions. The arm is equipped with six degrees-of-freedom (dof) and has a length of approximately 1 m. The length of the arm and its mounting position on the mobile base enable the manipulator to sweep the floor in its elbow-down configuration, and reach a typical counter-top level with its elbow-up configuration. An object positioned in a volume of approximately 30 cm \times 50 cm \times 120 cm, located at a distance 30 cm from the mobile base, can be reached by the arm with sufficient dexterity to permit delicate and precise actions.

The gripper actuator is located next to the actuator of the wrist pitch, so that the fingers can grasp an object with their internal surfaces as well as with their external surfaces. This feature allows the use of different finger profiles, suited for holding objects of different shapes and dimensions.

The key element of the manipulator is the gear-motor assembly powering each joint. This assembly is a modular configuration that can be scaled according to the design needs. The original design was developed for the *Rocky 7* Mars Rover [18], and is used for the wrist pitch and yaw and the finger actuators.



Figure 3: The manipulator arm in its folded position.

The wrist roll design is derived from the Serpentine Manipulator developed at JPL [10]. The elbow and the shoulder joints are more powerful versions of the wrist joints, but still highly backdrivable and with zero backlash. We are currently in the process of mechanizing the arm with a small PC, following the approach described in [7].

5 The User Interface

The user interface for the Health Care Robot, shown in Figure 4, displays the data collected by the robot and accepts different types of user commands.

Data from the robot include video images from the robot-mounted camera, sonars readings, position of the robot on a map of the environment, and voice commands. In addition, the interface can display images from other sources, such as a remote physician or a relative, connected via video-conferencing.

The data-entry portion of the Graphical User Interface is shown in Figure 5, and consists of five components: voice interface, velocity control, status indi-



Figure 4: The mobile robot and the operator interface.

cator, sonar display, and voice/joystick control mode selection.

Currently, the two main modes for controlling the robot are voice commands and joystick inputs, selectable by checking the *Use Joystick* check box. For the elderly and the handicapped, the usage of keyboard and mouse may present a difficult problem. Voice input as the main control modality offers several advantages: (i) it is a natural means of communication, (ii) in certain cases of disability, it is the only communication channel available, (iii) it requires no physical linkage, and (iv) it can be readily optimized to the user's personal needs. For people with reasonable manual control, a joystick represents a good alternative to voice commands. The motion control is aided by the video feedback from the robot camera, which always points towards the direction of motion. The user has a direct view of the environment in front of the robot, and a good perception of possible obstacles.

Additional methods for commanding the robot will become more important when map registration and self-localization capabilities are available. For example, a map of the environment showing the location of the robot will allow the user to specify the target position with the mouse, relying on the robot to autonomously plan and execute the trajectory. It will also be possible to specify a target by voice commands.

The following sections give a more detailed description of the components of the user interface.

5.1 Feedback to the User

The main source of information about the environment surrounding the robot is the output of the color camera installed on the robot. We are currently experimenting with two methods for sending images in real-time from the robot to the control station. The first method uses the eXceed package [11] for creating an *X* client on the control station to display the camera images. Since images are transmitted without any compression, this method provides only sub-Hertz refresh rate. We are also experimenting with the *Vic* video-conferencing software [12] which uses the Intra-H.261 compression scheme, and achieves refresh rates of up to 30 frames per second.

A second type of visual feedback is provided by displaying two maps of the robot environment. The bottom square of Figure 5 represents the robot position on the map of a laboratory room, whereas the top square of the Figure shows a map relative to a coordinate frame fixed to the robot. This map displays the robot's sonar readings as rays emanating from the circle representing the robot. The length of each ray represents the distance measured by the corresponding sonar to an obstacle near the robot. Sonar readings are updated at a rate of about 1 *Hz*.

Robot status and voice commands are repeated to the user. The status is displayed by a text field, shown on top of Figure 5, and consisting of the last voice command or of the indication of joystick mode. Voice commands are also repeated back to the user for confirmation.

5.2 Voice Commands

The main command mode is the voice interface, whose core is a *voice recognition engine* carrying out the interpretation of the user's utterances. If a correct match is found, the function associated to the command is activated in the robot. At the present time, the voice interface recognizes the following commands: *Stop*, *Rotate Left*, *Rotate Right*, *Turn Right*, *Turn Left*, *Left*, *Right*, *Move Forward*, *Move Backward*, *Step Forward*, *Advance 1 to 10*, *Go To Sleep*, *Ready*, and *Attention*.

The *Rotate* and *Move* commands move the robot indefinitely until the *Stop* command is given. The *Turn* commands rotate the robot by 90°, whereas *Left* and *Right* turn the robot by 10°. *Step Forward* moves the robot forward .5 *m*, *Advance 1 to 10* moves the

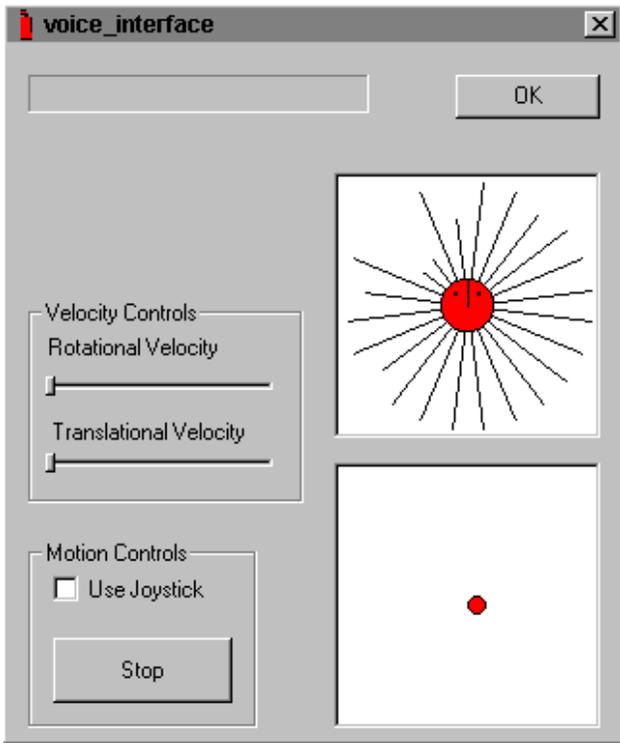


Figure 5: Health Care Robot Graphical User Interface.

robot forward by the number of meters given by the numerical parameter.

The voice interface is enabled by the *Go To Sleep*, *Ready*, and *Attention* commands. The *Sleep* command forces the voice interface to respond only to the *Ready* command, thus preventing background conversations from accidentally operating the robot. When asleep, the voice interface is enabled only by the sequence *Ready Attention*, thus providing a two-level safety protection. If the sequence is not received correctly, the robot returns to the sleeping state.

5.3 Joystick Commands

Joysticks are commonly used control devices for motorized wheel chairs, and we included this control method in the HCR interface to capitalize on possible user's skills. The result is a *virtual wheelchair* behavior, which replaces the user's direct view of the environment with the images fed back by the robot camera.

The interface can be switched between voice and joystick command mode by clicking the lower-left button in the interface shown in Figure 5. The forward-backward joystick motion corresponds to the forward-backward motion of the robot, the side-to-side motion

corresponds to the robot rotation, and a slider on the joystick is used for setting the robot velocity. Because of the non-holonomic constraint of the platform a diagonal motion is executed by first moving the joystick sideways to position the robot in the desired direction, and then by pushing the joystick forward to initiate the motion.

5.4 Mouse Commands

This command mode is reserved for parameter setting, emergency stop, and map-based position commands. The two sliders shown in Figure 5 set the rotational and translational velocities of the robot when the interface is in voice mode. The *Stop* button in the graphical interface halts the robot, regardless of its current mode, thus providing an emergency stop capability similar to the stop switches on the robot.

Map-based position commands are initiated by positioning the cursor in the window displaying the map of the environment. The position of the cursor specifies the robot target. Then, by clicking the mouse button, the user can command the robot to reach the target. During motion, the robot autonomously avoids the obstacles along the path.

6 Conclusions

This paper presents a progress report on our current work at JPL on mobile robots for the assistance to the elderly and the handicapped. We combined a mobile robotic platform with a 6-dof manipulator arm, and developed a low-cost control station for operating the mobile robot. The control station is capable of interpreting voice, joystick, and mouse commands, and displays real-time images from the robot camera, a schematic map of the environment, and the reading of the robot ultrasonic sensors.

The proposed system responds to the needs of the health care community for a low-cost robotic aide which can perform simple home assistance functions, and selected tasks in medical facilities. We are currently in the process of evaluating the utility of the system and the accessibility of the control station with potential users of the robot, including administrators, medical personnel, and patients.

In the future, we plan to add more powerful input-output capabilities to the user interface, and to develop the relevant command, control and safety procedures for the mobile manipulator, and to demonstrate simple fetch-and-carry tasks under voice control.

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